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Thermal Destruction of Hazardous Waste

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THERMAL DESTRUCTION OF HAZARDOUS WASTE

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16. ABSTRACT

Since 1982, the U.S. Environmental Protection Agency (EPA) has been conducting performance assessments of hazardous waste thermal destruction facilities in the United States. The principal objective of these tests has been to characterize emissions and determine if these facilities are capable of meeting the waste destruction and control requirements of the current EPA regulations and standards. To date the test program has involved performance assessments at nine incinerators and over twenty high temperature industrial processes employing hazardous waste as a fuel supplement in their operations.

The testing has typically involved stack emissions assessment for SO_x, NO_x, particulate, HCl, CO, CO_2, O_2, metals, total hydrocarbon, and quantification of specific organic compound emissions. Engineering and other process operating varibles (e.g., excess air, steam load, waste to fuel ratio) have also been recorded during the test program in order to examine the potential operating bounds for these facilities.

The purpose of this paper is to summarize the extensive results of this testing program which has, in general, indicated that high organic compound destruction and removal efficiencies (99.99 percent) are achievable in these facilities. Effective (99 percent) control of HCl emissions was attained in facilities employing chlorinated organic wastes. The current EPA particulate standard of 180 mg/dry m^3 was the most difficult standard to attain for incinerators.

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small business in handling their wastes responsibly and economically.

This report describes thermal destruction technology applicable to the disposal of hazardous wastes, including: principles of operation; important factors in design and operation; and typical air pollution control systems. Current thermal destruction practice in the United States is also profiled. Finally, data are presented on the performance of thermal destruction processes including high temperature incinerators and industrial furnaces where hazardous wastes are used as a fuel supplement.

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ABSTRACT

Since 1982, the U.S. Environmental Protection Agency (EPA) has been conducting performance assessments of hazardous waste thermal destruction facilities in the United States. The principal objective of these tests has been to characterize emissions and determine if these facilities are capable of meeting the waste destruction and control requirements of the current EPA regulations and standards. To date the test program has involved performance assessments at nine incinerators and over twenty high temperature industrial processes employing hazardous waste as a fuel supplement in their operations.

The testing has typically involved stack emissions assessment for SO_x, NO_x, particulate, HCl, CO, CO_2, O_2, metals, total hydrocarbon, and quantification of specific organic compound emissions. Engineering and other process operating variables (e.g., excess air, steam load, waste to fuel ratio) have also been recorded during the test program in order to examine the potential operating bounds for these facilities.

The purpose of this report is to profile thermal destruction technology, current practice in the United States, design considerations, and to summarize the extensive results of this testing program. In general, testing has indicated that high organic compound destruction and removal efficiencies (99.99 percent) are achievable in these facilities. Effective (99 percent) control of HCl emissions was attained in facilities handling chlorinated organic wastes. The current EPA particulate standard of 180 mg/dry m^3 was the most difficult standard to attain for incinerators.

KEY WORDS: hazardous waste, incinerators, industrial boilers, cement kilns, emission sampling, trace organic compounds, thermal destruction.

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THERMAL DESTRUCTION OF HAZARDOUS WASTE

A. Introduction

Thermal destruction of hazardous waste involves the controlled exposure of waste to high temperature (usually 900°C or greater), and typically, an oxidizing environment. Thermal destruction processes include: thermal oxidation, starved air, or pyrolytic incineration systems; high temperature industrial proceses such as boilers, cement kilns, and industrial furnaces where hazardous waste is employed as a fuel; and various emerging processes which employ high temperatures, such as molten salt, plasma, or electric furnaces.

Properly designed and operated thermal destruction systems offer the prospect of destroying the hazardous organic components of waste streams while reducing waste volume and, in some instances, recovering energy or even materials such as hydrochloric or surfuric acid. Because of this, thermal destruction systems have emerged over the past decade as an increasingly desirable alternative to the more traditional hazardous waste disposal methods of landfilling, lagooning, and deep well injection.

However, improper design, operation, or use of such systems may also pose a threat to public health through emissions of potentially hazardous components of the waste or their combustion by-products. It was the recognition of the inherent environmental advantages of waste thermal destruction, balanced against the potential problems of improper practice that lead the U.S. Environmental Protection Agency (EPA) to develop performance standards and permit requirements for thermal destruction systems under the Resource Conservation and Recovery Act of 1975 (RCRA). Standards for incinerators have been in place since June

1982 and standards are currently under development for disposal of hazardous wastes in industrial processes.

It is anticipated that thermal destruction will become even more important in the future as EPA responds to the U.S. Congressional mandate to restrict many hazardous wastes from land disposal and to effect corrective action at abandoned and uncontrolled disposal sites under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA).

The objective of this report is to profile the current status of thermal destruction in the United States including facilities, general design factors, wastes typically handled, and process performance data.

B. The Thermal Destruction Process

(1) Incineration

The most common approach to thermal destruction is incineration. Incineration is an engineered processs that employs thermal destruction via thermal oxidation at high temperature (900°C or greater) to convert a waste to a lower volume, nonhazardous material. To be a functional candidate for destruction by incineration, the waste itself, or at least its principal hazardous components, must be combustible. Ideally, the primary overall products from the combustion of organic wastes are carbon dioxide (CO_2), water vapor, and inert ash. However, with most hazardous wastes and incineration systems there are a multitude of other products which may be formed, depending upon the chemical composition of the waste material incinerated and combustion conditions encountered.

Hydrogen chloride (HCl) and small amounts of chlorine (CL_2), for example, are formed from the incineration of chlorinated hydrocarbons. Hydrogen fluoride (HF) is formed from the incineration of organic fluorides, and both

hydrogen bromide (HBr) and bromine (Br_2) are formed from the incineration of organic bromides. Sulfur oxides (SO_x), mostly as sulfur dioxide (SO_2), but also including 1 percent to 5 percent sulfur trioxide (SO_3), are formed from the sulfur present in the waste material and auxiliary fuel. Highly corrosive phosphorus pentoxide (P_2O_5) is formed from the incineration of organophosphorus compounds. In addition, nitric oxides (NO_x) may be formed by thermal fixation of nitrogen from nitrogen compounds present in the waste material. Suspended particulate emissions are also produced and include particles of mineral oxides and salts from the mineral constituents in the waste material, as well as fragments of incompletely burned combustible matter.

By-products from the incineration of hazardous wastes may also arise as a result of incomplete combustion and from combustion of constituents present in the wastes and combustion air. The incomplete combustion products include carbon monoxide, carbon, hydrocarbons, aldehydes, ketones, amines, organic acids, polycyclic organic matter (POM), and any other waste constituents or their partially degraded products that escape thermal destruction in the incinerator. In well designed and operated incinerators, these incomplete combustion products are emitted in insignificant amounts. However, in inadequate systems, they may be of enviromental concern.

As a consequence of the potential for the production of combustion by-products, hazardous waste incineration systems are designed to include a variety of air emission control devices. In most cases, this involves the use of afterburners or scrubbers. Afterburners are used to control the emission of uncombusted organic by-products by providing additional combustion volume (and thereby combustion time) at elevated temperature. Scrubbers of various types

operate by physically removing particulate matter, acid gases, and residual organics from the combustion gas stream. These devices will be described later.

(2) Important Factors In Incinerator Design And Operation

The most important factors for proper incinerator design and operation are combustion temperature, combustion gas residence time, and the efficiency of mixing of the waste with combustion air and auxiliary fuel. These parameters vary with a waste's chemical structure, physical form, and the type of incineration technology employed.

The chemical and thermodynamic properties of the waste that are important in determining its time/temperature requirements for destruction are its elemental composition, its net heating value, and any special properties (e.g., explosive or corrosive properties) that may interfere with incinerator operation or require special design considerations. The percentage of carbon, hydrogen, oxygen, nitrogen, sulfur, halogens, and phosphorus in the waste, as well as its moisture content, need to be known to determine stoichiometric combustion air requirements and to predict combustion gas flow and composition (factors in air emission control system design).

In general, higher heating values are required for solids versus liquids versus gases. Higher heating values are required to achieve higher operating temperatures, and for higher excess air rates, if combustion is to be sustained without auxiliary fuel consumption. While sustained combustion is possible with heating values as low as 4,000 Btu/lb (2,222 calories/gram), in the hazardous waste incineration industry it is common practice to blend wastes (and fuel oil, if necessary) to an overall heating value of 8,000 Btu/lb (4,444 calories/gram). Blending is also used to maintain the net chlorine content of chlorinated

hazardous waste to a maximum of roughly 30 percent by weight to limit free chlorine concentrations in the combustion gas.

The prediction of time/temperature requirements for achieving specific target levels of waste destruction efficiency is a very difficult task. While, in broad terms, highly halogenated materials are more difficult to destroy than those with low halogen content, data on specific waste/incinerator/operating condition combinations are only just beginning to emerge. Laboratory-scale thermal decomposition profiles can be used to determine the relative impacts of residence time, temperature, and combustion environment upon the thermal destruction components of waste streams. These data must then be confirmed and correlated with pilot- and full-scale testing.

Mixing is also an important design and operating factor. Adequate mixing insures that waste, hot combustion gases, and combustion air come into intimate contact with each other and that all waste particles have adequate residence time in the combustion zone to allow destruction to occur. This is accomplished by the use of high efficiency burners, the atomization of waste liquids into fine droplets (usually to 40$_{\mu}$ in diameter or less), and the control of excess combustion air (i.e., in excess of stoichiometric requirements) to maintain a high degree of turbulence in the combustion reactor.

(3) Incineration Technology

Three types of technology dominate the incineration field. Over 90 percent of the incineration facilities in the United States today are either liquid injection, fixed hearth, or rotary kiln incinerators. Of these nearly 70 percent are liquid injection units. Other types of incinerators include fluidized beds and moving hearth systems. Typical operating ranges for the

four major technologies are shown in Table 1. Table 2 compares the applicability of these technologies to a variety of waste types.

Liquid injection incinerators, as the name implies, are applicable almost exclusively for pumpable liquid waste. These incinerators (see Figure 1) are usually simple, refractory-lined cylinders (either horizontally or vertically aligned) equipped with one or more waste burners. Liquid wastes are injected through the burner(s), atomized to fine droplets, and burned in suspension. Burners as well as separate waste injection nozzles may be oriented for axial, radial, or tangential firing. Improved utilization of combustion space and higher heat release rates however, can be achieved with the utilization of swirl or vortex burners or designs involving tangential entry.

Vertically aligned liquid injection incinerators are preferred when wastes are high in inorganic salts and ash content while horizonal units may be used with low ash waste. The typical capacity of liquid injection incinerators is roughly 10×10^6 Btu/hr (2.5×10^6 kcal/hr) heat release. Units, however, range as high as 70 to 100 $\times 10^6$ Btu/hr (17.6 to 25.2 $\times 10^6$ kcal/hr).

Rotary kiln incinerators (Figure 2) are more versatile incinerators in the sense that they are applicable to the destruction of solid wastes, slurries, and containerized waste as well as liquids. Because of this, these units are most frequently incorporated into commercial off-site incineration facility design. The rotary kiln is a cylindrical refractory-lined shell that is mounted on a slight incline. Rotation of the shell provides for movement of waste through the kiln as well as for enhancement of waste mixing.

To insure complete waste combustion, rotary kiln incinerator designs normally include an afterburner. The primary function of the kiln is to convert

TABLE 1

TYPICAL OPERATING RANGES FOR INCINERATION PROCESSES

TYPE	CAPACITY LB/HR	CAPACITY MBTU/HR	TEMPERATURE °C (°F)	GASEOUS RESIDUE TIME
Liquid Injection	1,600	9	549-1593 (1200-2900)	0.1 - 2 Seconds
Fixed Hearth	800	5	482-982 (900-1800)	0.5 - 2 Seconds
Rotary Kiln	1,600	10	816-1593 (1500-2900)	0.5 - 2 Seconds (Gas) Hours (Solids)
Fluidized Bed	31,000	45	454-982 (850-1800)	0.5 - 2 Seconds (Gas) Minutes (Solids)

TABLE 2

APPLICABILITY OF AVAILABLE INCINCERATION PROCESSES TO INCINERATION OF HAZARDOUS WASTE BY TYPE

Waste Type	Rotary Kiln[a]	Liquid Injection	Fluidized Bed[a]	Fixed Hearth (Controlled Air)
Solids:				
Granular, homogeneous	X		X	X
Irregular, bulky (pellets, etc.)	X			X[b]
Low melting point (tars, etc.)	X	X[c]	X	X
Organic compounds with fusible ash constituents	X			X
Unprepared, large, bulky material	X			
Gases:				
Organic vapor laden	X[d]	X[d]	X[d]	X[d]
Liquids:				
High organic strength aqueous wastes often toxic	X[e]	X	X	
Organic liquids	X[e]	X	X	
Solids/liquids:				
Waste contains halogenated aromatic compounds (1,204°C minimum)	X	X[f]		
Aqueous organic sludge	X[g]		X	

a Suitable for pyrolysis operation.
b Handles large material on a limited basis.
c If material can be melted and pumped
d If properly presented to the incinerator.
e If equipped with auxiliary liquid injection nozzles.
f If liquid.
g Provided waste does not become sticky upon drying.

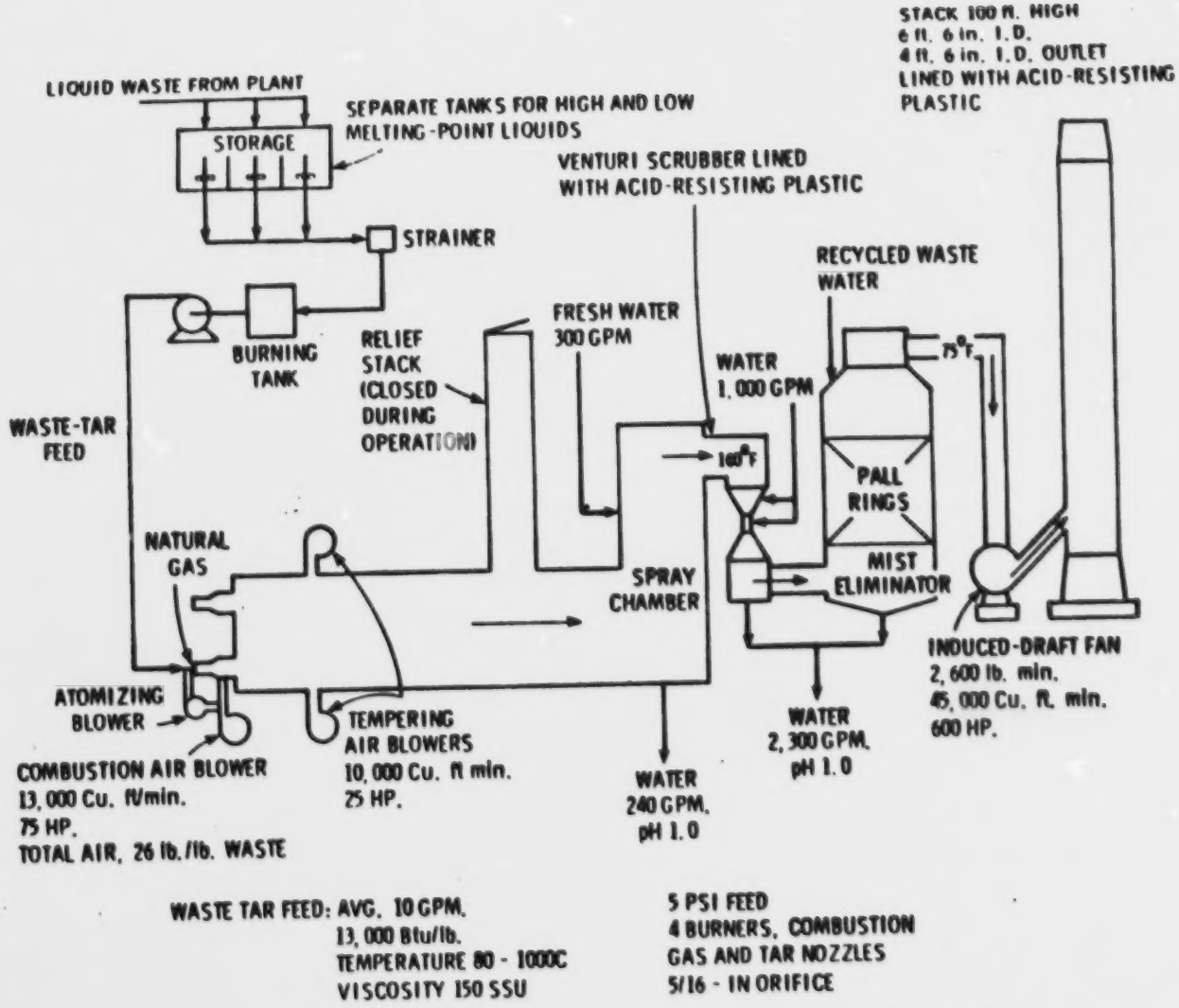


FIGURE 1: EXAMPLE OF A HORIZONTALLY-FIRED LIQUID INJECTION INCINERATOR SCHEMATIC

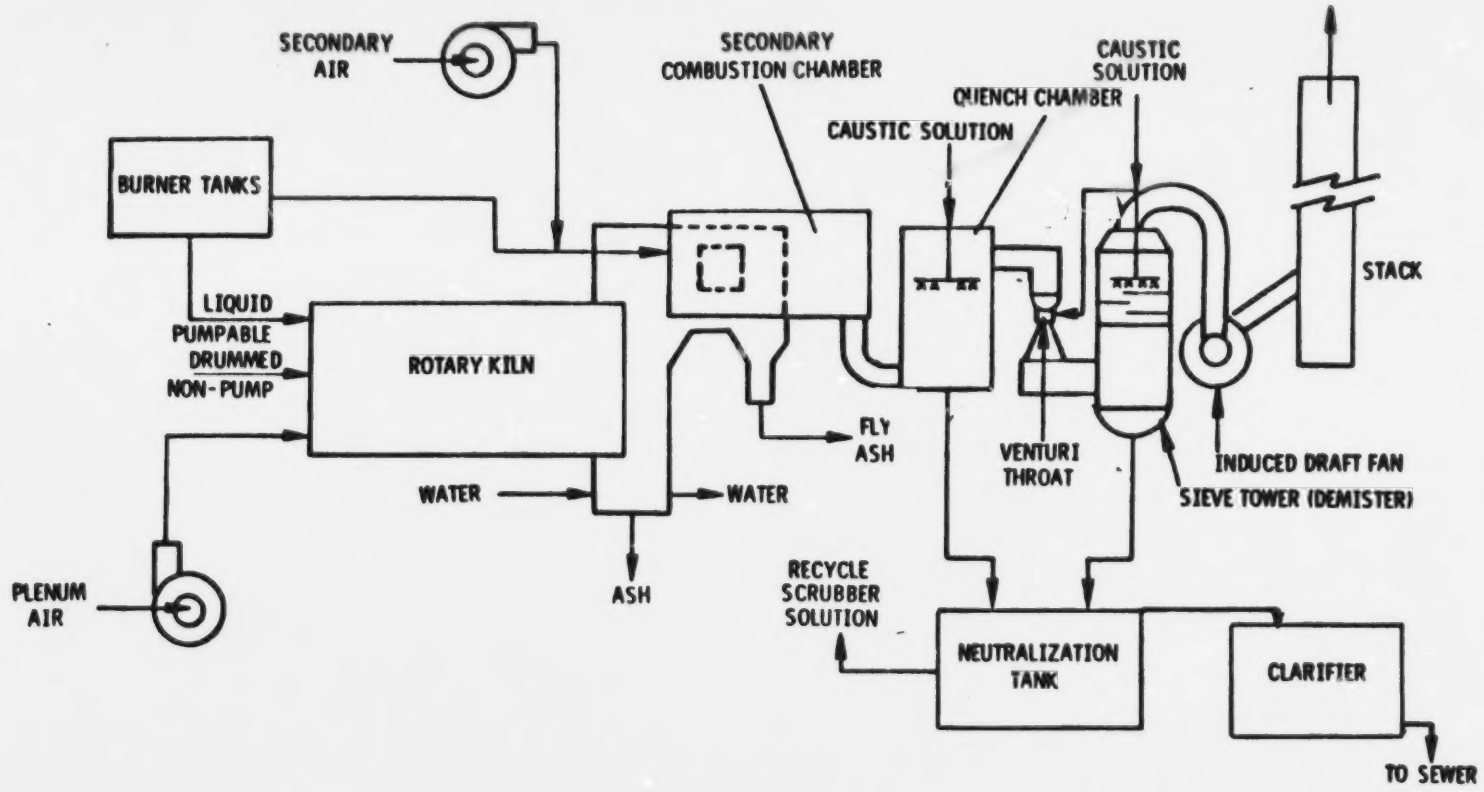


FIGURE 2: FLOW DIAGRAM OF AN EXAMPLE ROTARY KILN INCINERATION SYSTEM

solid wastes to gases, which occurs through a series of volatilization, destructive distillation, and partial combustion reactions. However, an afterburner is almost always required to complete the gas-phase combustion reactions. The afterburner is connected directly to the discharge end of the kiln. Typically, the gases exiting the kiln turn from a horizontal flow path to a vertical flow path upwards to the afterburner chamber. The afterburner itself may be horizontally or vertically aligned. Both the afterburner and kiln are usually equipped with an auxiliary fuel firing system to bring the units up to the desired operating temperatures. Rotary kilns are designed with a typical heat release capacity of 25×10^6 Btu/hr (6.3×10^6 kcal/hr).

Fixed hearth incinerators, also called controlled air, starved air, or pyrolytic incinerators, are the third major technology in use for hazardous waste incineration today. First marketed in the early 1960's, these units have seen rapid growth in use, particularly for "companies disposing of their own solid wastes within company grounds." Today, there are several thousand operating controlled air incinerators in the United States.

Controlled air (fixed hearth) incineration is basically a two-stage combustion process. A cut-away view of a typical unit is shown in Figure 3. Waste is ram fed into the first stage, or primary chamber, and burned at roughly 50 to 80 percent of stoichiometric air requirements. This starved air condition causes most of the volatile fraction to be destroyed pyrolytically, with the required endothermic heat provided by the oxidation of the fixed carbon fraction. The resultant smoke and pyrolytic products, consisting primarily of volatile hydrocarbons and carbon monoxide, along with products of combustion, pass to the second stage, or secondary chamber. Here additional air is injected to complete

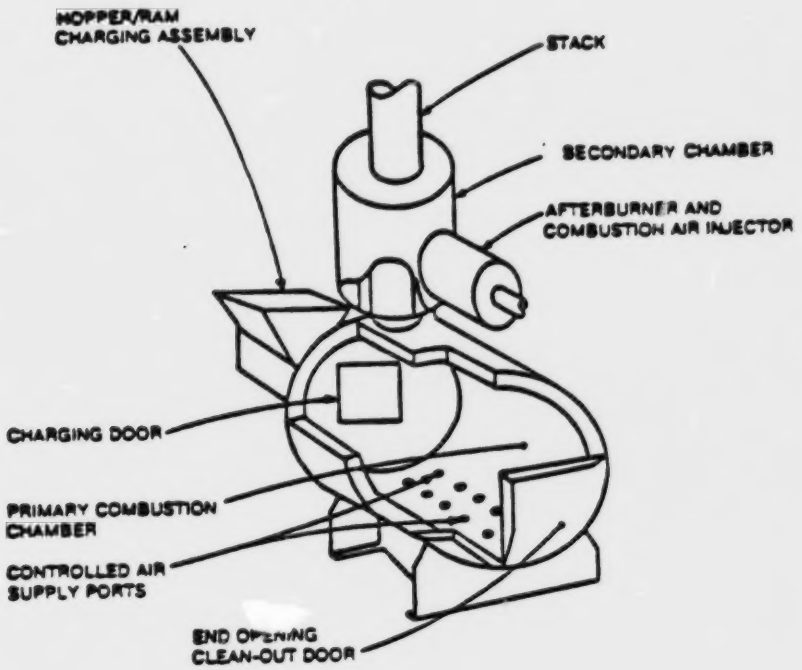


FIGURE 3: CUT AWAY OF A CONTOLLED AIR INCINERATOR

combustion, which can occur either spontaneously or through the addition of supplementary fuels. It is this two-stage process that allows low stack emissions. The primary chamber combustion reactions and turbulent velocities are maintained at such low levels by the starved air conditions that particulate entrainment and carryover is minimized. With the addition of secondary air, total excess air for controlled air incinerators is in the 100 to 200 percent range.

Secondary chambers of controlled air incinerators are generally designed to provide gas residence times from 0.5 to 1.0 seconds (0.7 seconds typically) and combustion temperatures ranging from 760°C (1400°F) to 982°C (1800°F), typically 871°C (1600°F). Longer residence times (up to 2.0 seconds) and temperatures up to 1204°C (2200°F) may be required, however, for systems burning many hazardous wastes.

Most controlled air incinerators are operated on a daily batch operating cycle, since they are often not equipped with automatic residue removal systems. The cycle involves residue clean-out from the previous day's charge; preheating; waste charging (generally with continuous ram feeders over an 8-hour period); burn down to assure complete burnout of residue; and a cool down cycle.

For hazardous waste incineration it is desirable, however, to use continuously operated units. This minimizes accidental release of hazardous materials during residue clean-out and will minimize thermal stress damage to refractories designed to withstand the higher temperatures often required for hazardous waste service.

(4) Incinerator Air Pollution Control Systems

As previously described, all hazardous waste incineration facilities generally require some form of combustion gas clean-up. Venturi scrubbers, packed

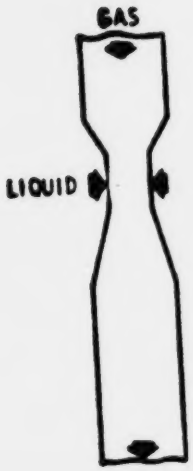
bed scrubbers, and plate tower scrubbers are used for particulate and gaseous pollutant control at the majority of hazardous waste incineration facilities (Figure 4).

Venturi scrubbers involve the injection of a scrubbing liquid (usually water or a water/caustic solution) into the exhaust gas stream as it passes through a high velocity constriction, or throat. The liquid is atomized into fine droplets which entrain fine particles and a portion of the absorbable gases in the gas stream.

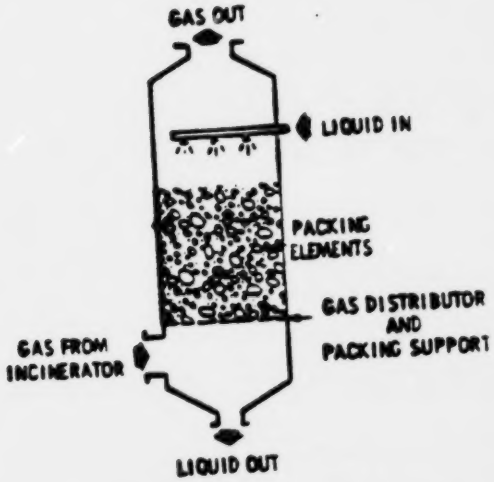
Contaminants are removed in packed bed scrubbers by a gas absorption process that depends on intimate gas/liquid contact. These scrubbers are vessels filled with randomly oriented packing material such as saddles and rings. The scrubbing liquid is fed to the top of the vessel, with the gas flowing in either concurrent, countercurrent, or crossflow modes. As the liquid flows through the bed, it wets the packing material and thus provides interfacial surface area for mass transfer with the gas phase.

Like packed bed scrubbers, plate scrubbers also rely on absorption for the removal of contaminants. The basic design is a vertical cylindrical column with a number of plates or trays inside. The scrubbing liquid is introduced at the top plate and flows successively across each plate as it moves downward to the liquid outlet at the tower bottom. Gas comes in at the bottom of the tower and passes through openings in each plate before leaving through the top. Gas absorption is promoted by the breaking up of the gas phase into small bubbles which pass through the volume of liquid in each plate.

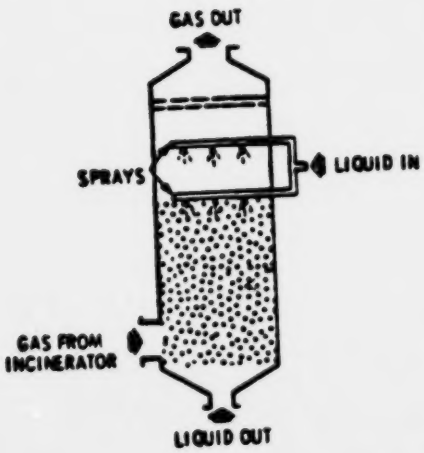
Packed bed or plate tower scurbbers are commonly used at liquid injection incinerator facilities, where absorption of soluble gaseous pollutants (HCl,



Venturi scrubber schematic.



Packed bed scrubber schematic.



Spray tower scrubber schematic

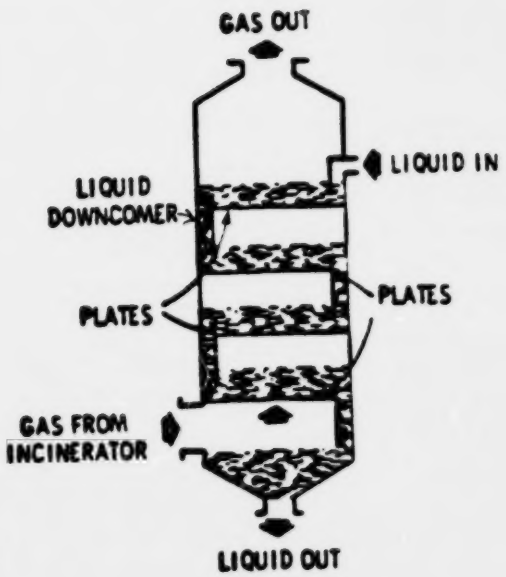


Plate tower schematic.

FIGURE 4: Incinerator Air Pollution Control Devices

SO_x, NO_x) is most important and particulate control is less critical. However, at rotary kiln or controlled air facilities, or liquid injection facilities where high ash content wastes are burned, heavier particulate emissions must be dealt with. Venturi scrubbers are the most popular devices for these applications. When combustion gases contain a high particulate loading as well as one or more of the gaseous pollutants above, venturi scrubbers are often used in series with packed bed or plate tower scrubbers.

(5) Incineration In High Temperature Industrial Processes

While the practice of controlled high temperature incineration in conventional or advanced thermal destruction processes is expected to increase, there is evidence that incineration of hazardous waste in high temperature industrial processes such as cement kilns and industrial boilers also plays a significant role in hazardous waste management.

There are two primary reasons for this. First, many existing industrial thermal processes provide temperature and residence time conditions similar to or in excess of those provided in typical incinerator designs (Table 3). Thus, where appropriate, cofiring of hazardous waste with conventional process fuel or substituting hazardous waste as fuel could become more cost-effective than the operation of separate waste incineration facilities because of the capital and operating cost savings and the potential for direct energy recovery from combustible wastes. Secondly, the current EPA hazardous waste regulations specifically exempt facilities that combust wastes in energy-producing operations from complying with regulatory performance standards. This obviously provides a incentive to industry to employ such processes to destroy certain hazardous waste streams and to recover their energy values where these wastes are compatible with their facilities.

TABLE 3

ALTERNATIVE INCINERATION PROCESSES AND THEIR TYPICAL OPERATING RANGES

INDUSTRY	PROCESS OR FURNACE	TEMPERATURE RANGE (°F)	RESIDENCE TIME (SECONDS)
Industrial Boilers	Fire Tube (Oil/Gas)	1990-2600	0.1-0.5
	Water Tube (Oil/Gas)	1600-2350	0.3-0.2
	Pulverized Coal	1900-2300	0.9-4.0
	Spreader Stoker	1650-2100	0.7-3.0
Cement	Cement Kiln (Wet)	2560-3600	6-10
Lime	Rotary Kiln	1265-3440	6-10
Iron And Steel	Blast Furnace	300-3400	1.8
	Open Hearth	2200-3250	2.0
Primary Copper	Multiple Hearth	390-1400	4.0
	Fluidized Bed	1000-1300	5-15
	Reverberatory	2300-2370	2.3
Primary Lead	Blast Furnace	1350-2200	5.6
Brick	Tunnel Kiln	1600-2600	1.0

The use of hazardous wastes as a fuel supplement in industrial boilers is a particularly attractive destruction alternative for many waste/boiler combinations. The opportunity for incineration of hazardous wastes in industrial boilers is great. There are over 40,000 industrial boilers in the United States with heat release capacities greater than 10×10^6 Btu/hr (2.52×10^6 kcal/hr), the average capacity of liquid injection incinerators. Most major industrial facilities which generate hazardous waste would be expected to have one or more boilers of at least this capacity.

The efficient destruction of combustible hazardous waste achievable in industrial boilers is primarily dependent on the temperature and residence time profiles of the combustion products as they pass through the furnace. The destruction efficiency of any species is maximized when the gas temperature and residence time are maximized. Since industrial boilers are nonadiabatic reactors, the temperature of the combustion products peaks in the flame zone and is reduced as heat is absorbed by the furnace walls. Thus, a representative temperature-time profile through the combustion zone is necessary to estimate the destruction potential for hazardous waste constituents.

The furnace gas exit temperature is also a vital design consideration. A furnace exit temperature of at least 1,000°C (1,880°F) is generally necessary to assure a sufficient time/temperature environment has been provided for high waste destruction efficiency. In the case of coal fired boilers employing hazardous waste as a fuel, the design flue gas temperature at the exit of the furnace is heavily dependent on coal type and its ash properties. For example, the design exit temperature at full load is normally 200°F less than the fusion temperature of the ash in the coal. This design criterion is imposed

to minimize fouling of the convective passes by deposition of molten coal ash on the heat transfer tubes. This design exit temperature, together with coal combustion characteristics, determines the overall size of the furnace and thus, the bulk residence time of the combustion products.

From a destruction standpoint, cement kilns are also a particularly attractive technology for cofiring of hazardous waste. Cement kilns typically operate at temperatures and gaseous residence times in excess of those provided in high efficiency hazardous waste incinerators. The combustion zone provides a high degree of mixing and turbulence necessary for waste destruction and the highly alkaline environment in the kiln serves to trap acid combustion gases and many heavy metals in the cement clinker, thus, potentially eliminating the need for special off-gas scrubbing systems.

C. Current Practices

The most recent comprehensive data on hazardous waste thermal destruction practice come from EPA surveys of industry activity in 1981. It is estimated that the United States generated 264 million metric tonnes (MMT) that year, a large portion of which was predominantly nonhazardous materials (water) contaminated with smaller amounts of hazardous materials. Over 5.5 MMT was managed by thermal destruction, with 1.7 MMT disposed in 240 incineration facilities and 3.8 MMT disposed in over 1300 industrial boilers and other industrial furnaces. EPA estimates that as much as 25 MMT of the waste generated in 1981 could have been directly managed by thermal destruction.

Hazardous waste incineration practice is more extensively documented than is waste disposal in industrial boilers and furnaces. Incinerators have been the subject of EPA research for nearly a dozen years. Regulation, notification,

and permit requirements have also produced a larger data base about incinerators. The practice of waste disposal as a fuel in industrial boilers and other industrial process furnaces will not be fully regulated until late 1986. Table 4 profiles United States incineration practice in 1981. The most commonly used design is the liquid injection incinerator.

Precise information on the exact types of wastes going to thermal destruction facilities is difficult to obtain. Many facilities operate on an intermittent basis and handle mixtures of wastes which are difficult to describe in terms of EPA standard waste codes. A 1983 EPA study examined data on 413 waste streams going to 204 of the 240 incineration facilities in the United States. Table 5 summarizes the findings.

In 1981, industrial furnaces disposed of more than twice the amount of waste than was disposed via incinerators. The most recent source of information on waste fuel use in industrial processes was compiled for EPA in 1984. The study synopsizes results of a national questionnaire of waste fuel and waste oil use in 1983. The study revealed that there were over 1,300 facilities using hazardous waste-derived fuels (HWDF), accounting for a total of 230 million gallons per year. The chemical industry accounted for 67 percent of this while operating only 12.4 percent of the facilities using HWDF. Other industries employing significant quantities of hazardous waste as fuel included: paper, petroleum, stone, clay, glass, concrete, and primary metals. The majority (69 percent) of waste was burned in large quantities by a few facilities representing only a fraction (1.6 percent) of the 1,300 facilities. These included medium- to large-sized industrial boilers, cement and aggregate kilns, and iron-making furnaces.

TABLE 4

UNITED STATES HAZARDOUS WASTE INCINERATION PRACTICES (1981)

OWNERSHIP:	80% private 20% commercial and military
WASTE:	77% of facilities handle on-site wastes only 79% of units - liquids only 11% of units - bulk wastes (solids and liquids) 10% of units - special purpose
EQUIPMENT:	48% are liquid injection units 19% are fixed hearth units 6% are rotary kiln or combination units 27% are other (military, fluid bed, etc.) 45% have air pollution control systems 22% employ heat recovery
OPERATIONS:	median - 982°C (1800°F) at 2 seconds residence time (gas) range - 649°C (1200°F)- 1260°C (2300°F) 0.1 seconds - 6.5 seconds residence time most operate on an intermittent schedule
CAPACITY:	median - liquids, 567.8 l/hr (150 gal/hr) solids, 294.8 kg/hr (650 lb/hr) range - 0.3 - 142 x 10^6 Btu/hr .075 - 35.78 x 10^6 KCal/hr
MANUFACTURING:	57 companies actively marketing incinerators 28 companies sold units most units installed since 1970 32-40 units under construction

TABLE 5

MAJOR WASTE STREAMS INCINERATED (1981)

	Number of Incinerators	Waste Quantity (Thousand) Metric Tons/Yr)
Ignitable Organic Liquids (D001)	69 (60)*	36
Contaminated Water (D001)	17 (17)	127
Corrosive, Reactive (D002, D003)	32 (30)	175
Spent Halogenated Solvents (F001, F002)	18 (11)	16
Spent Nonhalogenated Solvents (F003)	22 (18)	212
Acrylonitrile Bottoms (K011)	3 (3)	109
Hydrocyanic Acid (P063)	6 (5)	123
39 Other Waste Streams	-	107
		905

*( ) Number Reporting Quantity

Waste-code-specific data on HWDF are not readily available. In general, however, of the HWDF burned in 1983, 30 percent was organic solvents, and 45 percent was other hazardous organics. Most of the waste was generated on-site and 74 percent of the balance arrived directly from an off-site generator rather than an intermediary.

D. Performance Of Thermal Destruction Devices

Until recently, there were only limited data available on waste destruction performance and pollutant emissions from thermal destruction devices. Studies by EPA and others in the 1970's employed a variety of evolving trace organic pollutant sampling and analysis techniques that were often geared to measuring macro-destruction and combustion efficiencies rather than the rigid performance requirements now required under RCRA. Since 1981, however, EPA has conducted a significant program of performance testing at thermal destruction facilities. The program was designed to provide information on the ability of these processes to destroy hazardous wastes to the degree required by the 1982 incinerator performance standards. These standards require that to obtain an operating permit, a facility must demonstrate that it can attain at least 99.99 percent destruction and removal efficiency (DRE) for each principal organic hazardous constituent (POHC) in the waste feed, at least 99 percent removal of hydrogen chloride from the exhaust gas if hydrogen chloride stack emissions are greater than 1 kg/hr (4 lb/hr) and particulate emissions no greater than 180 g/Nm^3 (0.08 grains/dscf), corrected to 7 percent oxygen in the stack gas.

(1) Sampling And Analysis

The primary objective of the field testing programs was to characterize the emissions of incinerators, industrial boilers, and industrial processes burning

hazardous waste under current industrial operating practices in order to determine the ability of these facilities to meet existing and proposed control standards. Accomplishment of this objective required that each input and output stream be characterized to the greatest extent possible. Sampling locations, sampling and analysis methods, quality assurance/quality control (QA/QC) planning followed established EPA guidelines, but were necessarily somewhat unique for each facility tested because of differences in system designs, operating practices, and waste characteristics. Typical input streams sampled included: waste feed, process feed (e.g., limestone feed to kilns), auxiliary or base fuel (in the case of boilers and kilns), and air pollution control system make-up and recycle waters. Output streams generally included: stack gases, air pollution control device effluent (solid or liquid), bottom residues (ash), or product (cement, lime, aggregate). Where appropriate, gas samples were collected before and after air pollution control devices to characterize their contribution to performance.

Figure 5 is an example schematic of a sampling protocol for one of the incineration systems tested. This illustrates the location of sampling points as well as the complexity involved in sampling many of the facilities.

Composited grab samples were employed for fuels, waste feed, ashes, residues, and product streams. Extractive sampling techniques were employed to collect integrated samples of combustion and stack gases. Semivolatile organic compounds (boiling points greater than 130°C) and particulates were collected using a modified EPA Method 5 (MM5) sampling train (Figure 6), with minor differences from site to site. Generally, organics were extracted from all portions of the sampling train, including the XAD-2 organic sorbent, filter media, and impinger

SAMPLING POINTS AT AN INCINERATOR

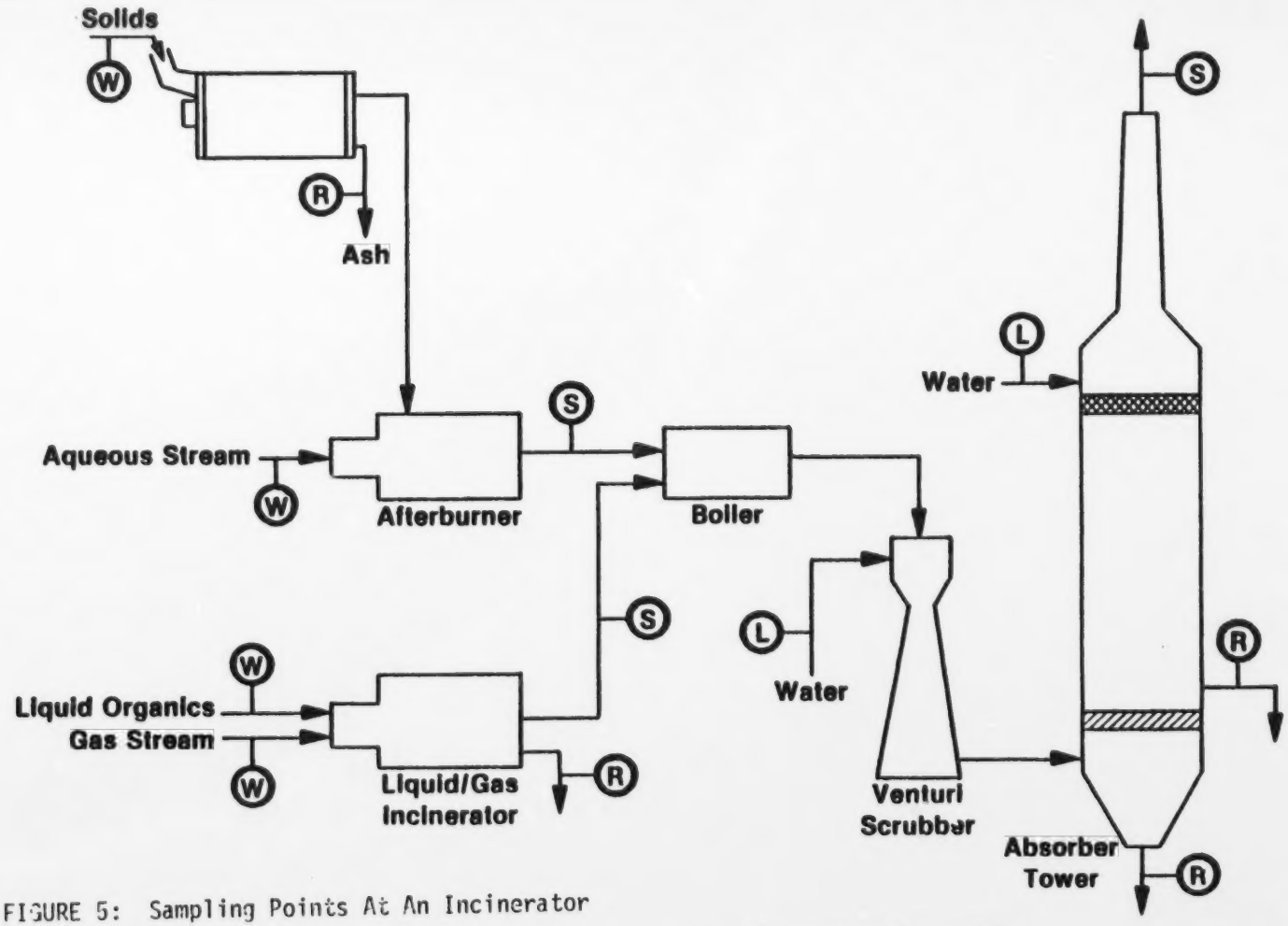


FIGURE 5: Sampling Points At An Incinerator

W = waste sampling points
S = gas sampling points
R = residue sampling points

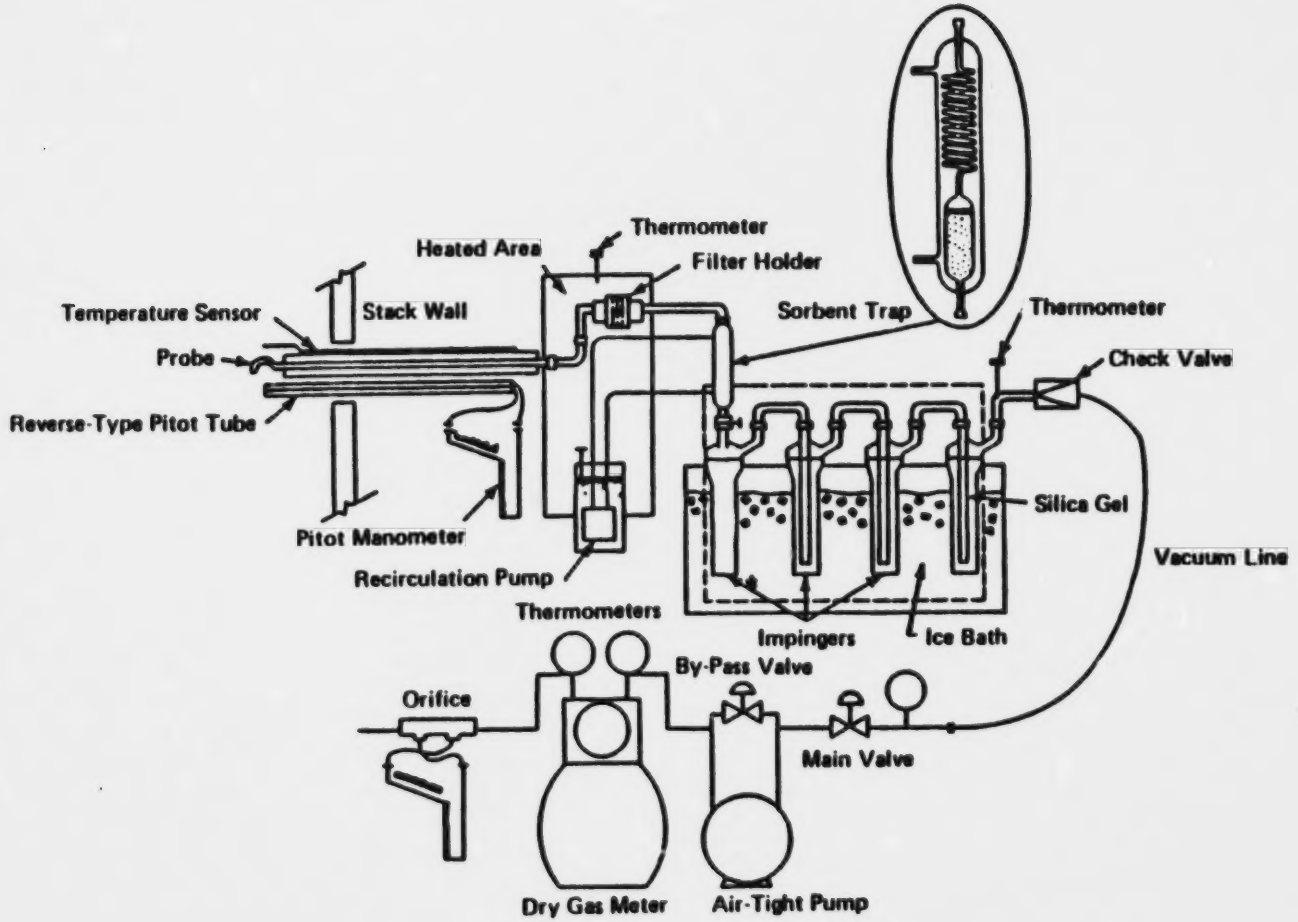


FIGURE 6: EPA MODIFIED METHOD 5 (MM5) SAMPLING TRAIN

solution. Volatile organics, those having boiling points <130°C, were generally sampled using the EPA volatile organic sampling trains (VOST), illustrated in Figure 7. However, because of the evolution of this new sampling train during the four-year period of the test program, certain sites were tested with single trap systems or gas bags. Volatile compounds were thermally desorbed from the TENAX resin employed in the VOST and subsequently analyzed by GC/MS, or GC/EC.

Stack and combustion gases were also monitored continuously for oxygen (O_2), carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_2), nitrogen oxides (NO_x), and in many cases, total hydrocarbons (THC). Grab samples of wastes and fuels were also analyzed for heating value, proximate and ultimate analysis, and viscosity.

Each stream sampled was generally analyzed for hazardous organic constituents, chlorides, particulate or ash and, in some cases, metals of concern. Organic analysis of waste, fuel, and stack emissions samples was accomplished by GC/MS, GC/ECD, or GC/FID depending upon the selected organic groups sought in the analysis. Metals were most typically analyzed using ion capture detection methods.

Engineering and operating data were also collected for each facility. These data included waste and fuel feed rates, scrubber wastes feed, recycle and wastage rates, temperatures, and gas flow rates at critical portions of the facility and production related data for industrial processes (e.g., load and steam rate for boilers, clinker production rate for kilns).

(2) Site Selection and Testing Rationale

Test sites were selected to evaluate waste destruction over as broad a range of facility design, operational principles, and waste characteristics as

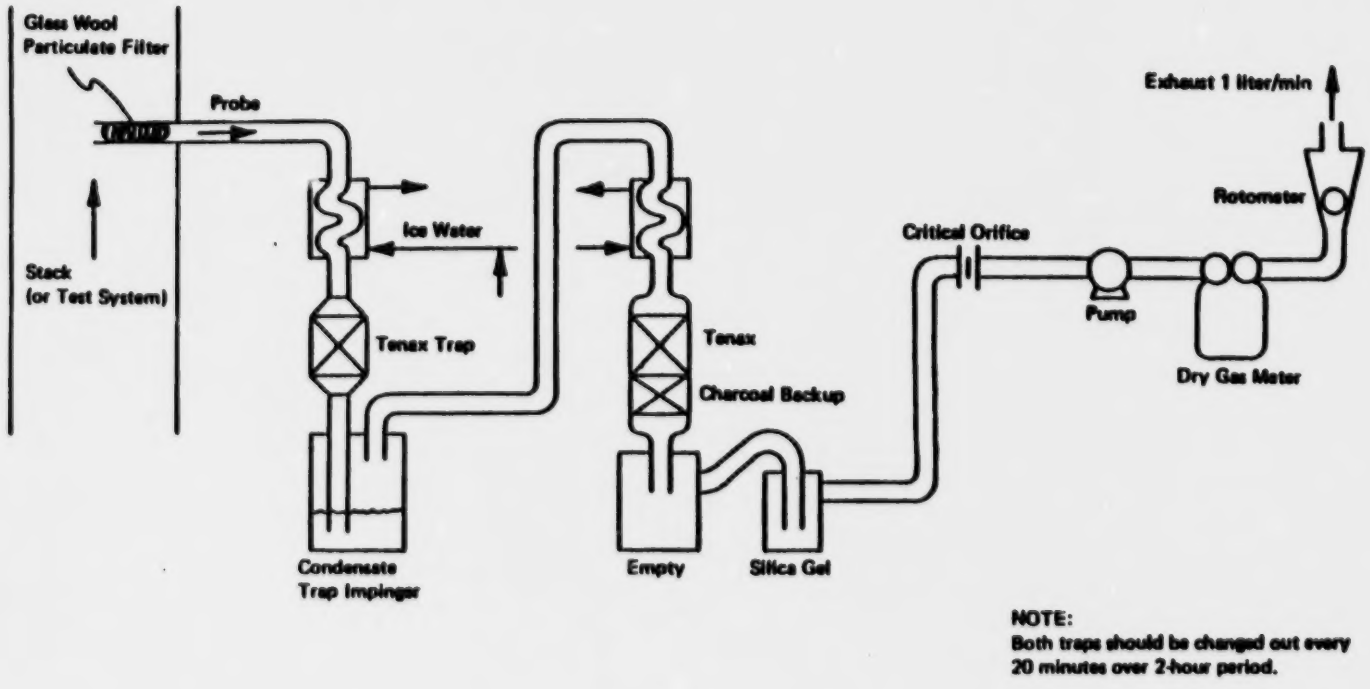


FIGURE 7: EPA VOLATILE ORGANIC SAMPLING TRAIN (VOST)

possible. This was necessary so that EPA could generalize testing results and conclusions to the whole spectrum of hazardous waste management activities which might come under the thermal destruction regulation.

In the case of incineration, eight facilities were selected, including both commercial and on-site units. The testing encompassed rotary kiln, liquid injection, and fixed hearth technologies. Table 6 provides an overview of other important aspects of these sites.

The facility capacities ranged from 1 to 87 GJ/hr heat input. Values for three key parameters: combustion temperature, residence time, and percent excess air or percent oxygen also varied widely. Operating temperatures ranged from 650°C to 1450°C and calculated residence times varied from 0.07 to 6.5 sec. Excess air values fell within a range of 60 to 130 percent. Corresponding oxygen values ranged from 8 to 12 percent.

Waste streams with a wide range of characteristics were encountered at the eight sites. The heating values were below 4,600 kJ/kg (2,000 Btu/lb) for aqueous liquids and ranged from 14,000 to 37,000 kJ/kg (6,000 to 16,000 Btu/lb) for organic liquids, and from 0 to 29,000 kJ/kg (0 to 12,500 Btu/lb) for solid wastes. The organic liquids and many of the solids had a high enough heating value to sustain combustion without auxiliary fuel. Percent chloride in the wastes ranged up to 25 percent, with the highest values occurring for organic liquids (chlorinated solvents). Little ash was found in aqueous liquids, values for organic liquids ranged up to 9 percent, and solids had the most ash with values from 17 percent to 29 percent. Water content is obviously high for the aqueous wastes, but ranged up to 50 to 60 percent for the organic liquids and solids. Operating conditions during the tests were those selected by the

TABLE 6--DESCRIPTION OF INCINERATION FACILITIES TESTED

FACILITY TYPE	CONTROL DEVICE	WASTE	CAPACITY (GJ/HR)	TEMPERATURE (°C)	RESIDENCE TIME (Sec)
(1) Commercial Rotary Kiln/ Liquid Incineratr	Packed Tower Adsorber Ionizing Wet Scrubber	Drummed, aqueous, liquid organic waste with carbon tetrachloride, TCE[a], perchloroethylene, toluene, phenol	87	1139	6.5
(2) Commercial Fixed Hearth, Two Stage Incinerator	Electrified Gravel Bed Filter And Packed Tower Absorber	Liquid organic and aqueous waste with chloroform, carbon tetrachloride, TCE, toluene, perchloroethylene	25	Stage 1 1063 Stage 2 1011	6.2
(3) On-site Two-Stage Liquid Incinerator	Packed Tower Absorber	Liquid organic waste with carbon tetrachloride, dichlorobenzene, TCE, chlorobenzene, chloromethane aniline, phosgene	6	1116	5.2
(4) Commercial Fixed Hearth, Two-Stage Incinerator	None	Liquid organic waste with TCE, carbon tetrachloride, toluene, chlorobenzene	2	Stage 1 705 Stage 2 868	.07
(5) On-Site Liquid Injection Incinerator	None	Liquid organic waste with aniline, diphenylamine, mono and dinitrobenzene	4.8	681	.20
(6) Commercial Two-Stage Fixed Hearth Incinerator	None	Aqueous and organic liquid waste with carbon tetrachloride, TCE, benzene, phenol, perchloroethylene, toluene, methylethyl ketone	10	Stage 1 1097 Stage 2 1100	2.3
(7) On-site Rotary Kiln With/Liquid Injection	Venturi Scrubber With Cyclone Separators And Packed Tower Absorbers	Liquid organic, point waste and filter cakes with methylene chloride, chloroform, benzl chloride, hexachloroethane, toluene, TCE, carbon tetrachloride	35	Stage 1 769 Stage 2 980 Liquid 1450	Kiln/AB 7.3 Liquid .26
(8) Commercial Two-Stage Fixed Hearth Incinerator	Venturi Scrubber	Aqueous and organic liquids and solid waste with methylene chloride, chloroform, carbon tetrachloride, hexachlorocylopentadiene, toluene, benzene, TCE	75	Stage 1 1092 Stage 2 1045	3.6

(a) TCE = trichloroethylene

plants as their normal conditions. In general, any obvious operating problems were corrected before the tests were initiated.

The industrial boiler facilities candidate test sites were screened based on representativeness of the boiler design and wastes being fired, and the availability and accessibility for cofiring tests. Within this context, preference was given to sites and waste fuels which were viewed as being less likely to attain a high level of waste destruction.

From a boiler design viewpoint, the test matrix addressed the major design categories of firetubes and watertubes and typical fossil fuels burned in these units. An earlier study on the estimates of time-temperature profiles in boilers had shown that although most boilers provide sufficiently high furnace temperature and residence time for efficient destruction of organic compounds, smaller units such as firetubes and small watertubes provide the least safety factor of time at high temperature.

Table 7 lists the eleven test sites selected for the field test program in the framework of the developed test matrix. The majority of the selected boilers were watertube designs in the 2.9 to 29 MW (10.4 to 104 GJ/hr) size category, employing either natural gas or heavy oil as the primary fuel. The waste fuels available at the selected sites were cofired as found. However, to facilitate intrasource comparison, the majority of test boilers were cofired with a "spike" mixture of organic compounds. Spiked compounds typically were carbon tetrachloride, chlorobenzene, and trichloroethylene, which were considered difficult to destroy. This practice was also employed in the incinerator and kiln tests, where carbon tetrachloride, trichlorethylene, and various freons were also employed.

TABLE 7--DESCRIPTION OF INDUSTRIAL BOILER FACILITIES TESTED

FACILITY TYPE	CAPACITY (GJ/HR)	PRIMARY FUEL	CONTROL DEVICE	WASTE
(1) Watertube Stoker	10	Wood Waste	Multiclone	Creosote Sludge With Phenol Pentachlorphenol And Naphthalene
(2) Packaged Firetube	8.5	Natural Gas	None	Alkyd Wastewater With Toluene
(3) Field Erected Watertube	230	Gas or Oil	None	Phenol Waste
(4) Converted Stoker	90	No. 6 Oil	None	Methanol, Toluene And Chlorinated Organics Including Perchloroethylene
(5) Packaged Watertube	110	No. 6 Oil	None	Methyl Methacrylate By-products With Carbon Tetrachloride, Chlorobenzene And TCE[a]
(6) Converted Watertube	60	No. 6 Oil	None	Paint Solvents With Carbon Tetrachloride, TCE, Toluene And Chlorobenzene
(7) Modified Firetube	40	None	2 Scrubbers In Series	Highly Chlorinated Organics Including Carbon Tetrachloride
(8) Tangentially Fired Watertube	250	Pulverized Coal	ESP	Methyl Acetate, Carbon Tetrachloride, Trichloroethane, Chlorobenzene
(9) Packaged Watertube	62	Natural	None	Aniline Waste With Nitrobenzene, Carbon Tetrachloride, TCE, Benzene, Toluene
(10) Packaged Firetube	10	None	None	Toluene, Chlorinated Organics, Including Carbon Tetrachloride, TCE
(11) Packaged Watertube	60	No. 6 Oil	None	Blended Waste With Light Oil And Carbon Tetrachloride, Benzene, TCE, Toluene

(a) TCE = trichloroethylene

The tests typically included a baseline test (primary fossil fuel only) followed by a minimum of three cofired tests for replication of results. Steady-state boiler operation was sought during all testing to minimize the variation in test parameters with potential impact on DRE's and other organic emissions.

Eight industrial kiln facilities were tested. Site selection here was limited to facilities actually employing hazardous waste fuels in their normal operations. As can be seen in Table 8 these included both wet- and dry-process cement kilns, a lime kiln, and three aggregate kiln facilities. The test matrix also was designed to cover a range of primary fuel type and air pollution control system design. Baseline tests (primary fuel only) and three replicate waste tests runs were employed as in the boiler evaluation program. Additionally, waste injection techniques were varied between the sites.

(3) Performance Results

Tables 9, 10, and 11 describe the facilities and waste types encompassed by the test program and summarize waste destruction and emission performance data. These test results are significant in that they reveal that well operated incinerators, industrial boilers, and process kilns are capable of achieving a 99.99 percent DRE. All of the incinerators tested achieved this level of performance for candidate POHC compounds in concentrations greater than 1000 parts per million (ppm) in the waste feed. Candidate POHC compounds below 500 ppm frequently were not destroyed to 99.99 percent.

This phenomenon, which was also observed in tests of other thermal destruction devices, was unexpected. A number of possible explanations have been advanced. At the very low stack emission concentrations necessary to demonstrate 99.99 percent DRE for sub-500 ppm POHCs, sampling and analysis techniques may be limiting. Also at these low emission levels, sufficient amounts of POHC may

TABLE 8--DESCRIPTION OF INDUSTRIAL KILN FACILITIES TESTED

FACILITY	CAPACITY (GJ/HR)	PRIMARY FUEL	CONTROL DEVICE	WASTE
(1) Wet Process Cement Kiln (Non-atomized Waste)	140	No. 6 Oil	Fabric Filter	Waste Liquids Including Methylene Chloride, Chloroform, Carbon Tetrachloride
(2) Wet Process Cement Kiln (Atomized Waste)	170	Coal	ESP	Waste Liquids Including Methylene Chloride, MEK[a], Trichloroethane, Toluene, Freon 113
(3) Dry Process Cement Kiln (Non-atomized Waste)	228	Coal/Coke	ESP	Waste Liquids Including Methylene Chloride, Freon 113, MEK, Toluene, Trichloroethane
(4) Dry Process Cement Kiln (Atomized Waste)	300	Coal/Coke	Fabric Filter	Waste Liquids Including Trichloroethane, Trimethylbenzene, Xylene, Methylene Chloride
(5) Lime Kiln (Atomized Waste)	50	Coke/Natural Gas	Fabric Filter	Waste Liquids Including Methylene Chloride, MEK, Trichloroethylene
(6) Shale Aggregate Kiln (Atomized Waste)	35	Coal	Scrubber	Waste Liquids Including Perchloroethylene, Methylethyl
(7) Clay Aggregate Kiln	20	Coal	Scrubbers	Waste Liquids Including Methylethyl Ketone, Perchloroethylene And Toluene
(8) Clay Products Kiln (Atomized Waste)	37.5	Waste Oil	Fabric Filter	Waste Liquids, Waste Oil, Freon 113, Perchloroethylene, Carbon Tetrachloride, Benzene Toluene, Trichloroethylene

MEK = methylethyl ketone

TABLE 9--INCINERATOR PERFORMANCE AND STACK EMISSIONS DATA

FACILITY TYPE	O_2 (%)	CO (ppm)	THC (ppm)	DRE(a) (NUMBER OF NINES)	PARTICULATE (mg/m^3)	HCl CONTROL
(1) Commercial Rotary Kiln/ Liquid Incinerator	10.5	<1.0-14.8	<1.0	5.3	1508	99.4%
(2) Commercial Fixed Hearth, Two Stage Incinerator	11.4	4.7 9.1	1.0	4.4	400	98.3%
(3) On-site Two-Stage Liquid Incinerator	8.3	9.9-11.2	3.9-8.9	4.4	61	99.7%
(4) Commercial Fixed Hearth, Two-Stage Incinerator	11	7.5 22.2	<1.0 1.9	4.7	200	<1.8 kg/hr
(5) On-Site Liquid Injection	12.1	6.7 19.3	<1.0	6.7	207	<1.8 kg/hr
(6) Commercial Two-Stage	9.9	<1.0 1.8	<1.0	4.8	900	<1.8 kg/hr
(7) On-Site Rotary Kiln	9.7	422-666	47.6-75.9	5.3	23	99.9%
(8) Commercial Two-Stage Fixed Hearth Incinerator	13.6	0.9-4.3	0.8-2.5	4.6	169	98.3%

(a) mass weighted overages for all POHCs >100 ppm in waste
4.5 nines = 99.995% DRE

TABLE 10--SUMMARY OF BOILER PERFORMANCE

Facility Type	Load (%)	O_2(%)	Residence Time (sec)	Average Volumetric Heat Release Rate KW//m^3	DRE[d] (No. Nines)	W/F[a] (%)	NO_x[b] (ppm)	CO[b] (ppm)
(1) Watertube Stoker	100	6-16	1.2	509	3.8	40	163-210	900-1200
(2) Packaged Firetube	25	4-6	0.8	739	4.1	0.1-05	40-65	47-88
(3) Field Erected Watertube	26	10	2	78	5.6	37	61-96	18-21
(4) Converted Stoker	78	4-6	1.1	339	4.8	18-48	193-250	75-127
(5) Packaged Watertube	36-73	6-7	0.5-1.1	960	4.5	19-56	164-492	83-138
(6) Converted Watertube	53	7-11	2	107	3.8	8.7-10.1	243-328	109-139
(7) Modified Firetube	44	8	0.4	807	4.8	100	67-74	146-170
(8) Tangentially Fired Watertube	100	6	2	180	4.1	2.4-4.3	393-466	142-201
(9) Packaged Watertube	65	2	1.8	343	4.8	8.2	64-78 410-1125[c]	46-750
(10) Packaged Firetube	50-100	3-8	0.3-0.7	1240	5.0	100	85-203	20-135
(11) Packaged Watertube	82	4	1.8	269	5.7	49	154-278	102-119

(a) W/F = waste heat input as a % of total heat input
(b) range of average values across individual sites and runs including baseline
(c) higher values are for high nitrogen waste firing
(d) DRE = destruction and removal efficiency (e.g., 4.5 nines = 99.995% DRE)

TABLE 11--SUMMARY OF INDUSTRIAL KILN PERFORMANCE

FACILITY TYPE	TEST[a]	DRE[b] (NO. NINES)	PARTICULATES[d] (kg/Mg)	HCl_1 (kg/hr)	NO_x (ppm)	SO_2 (ppm)	W/F(%)[c]
(1) Wet Process Cement Kiln (Non-atomized Waste)	W	2.2	.27	.36	68	450	25
	B	-	.26	.09	136	279	-
(2) Wet Process Cement Kiln (Atomized Waste)	W	4.6	.27	2.1	478	265	15
	B	-	.26	.6	371	636	-
(3) Dry Process Cement Kiln (Non-atomized Waste)	W	4.8	-	11.5	814	19	45
	B	-	-	1.3	620	7	-
(4) Dry Process Cement Kiln (Atomized Waste)	W	4.2	-	.47	486	27	15
	B	-	-	.25	680	27	-
(5) Lime Kiln (Atomized Waste)	W	4.7	.11	.20	446	596	30
	B	-	.10	.09	386	553	-
(6) Shale Aggregate Kiln (Atomized Waste)	W	>4.0	.33	2.1	-	-	100
(7) Clay Aggregate Kiln (Atomized Waste)	W	4.8	0.58	0.023	162	1130	59
(8) Clay Products Kiln (Atomized Waste)	W	>4.0	.002	0.84	-	-	100

(a) W = waste testing, B = baseline (no waste firing)

(b) DRE = destruction and removal efficiency (e.g., 4.5 nines = 99.995%)

(c) % of total heat input provided by waste fuel

(d) Stack emissions of particulate matter expressed as kg of emission per Mg of clinker produced

actually be formed as an incomplete combustion or recombination by-product of other materials in the wastes to produce sub-99.99 percent DRE.

EPA is conducting research to assess this concentration phenomenon. From a regulatory standpoint, however, this is not currently perceived as a problem since few if any of the low concentration compounds in the wastes identified in the EPA test program would have actually been selected as POHCs in trial burns, if existing EPA guidance on POHC selection were employed.

Industrial boilers, particularly the larger water tube units, are acceptable devices for waste destruction. Cement kilns, lime kilns, and light weight aggregate kilns with adequate combustion control and waste atomization all met or exceeded the 99.99 percent DRE. It is also important to note that for all of the incinerators and industrial processes tested, the destruction and removal efficiencies observed were due to destruction rather than removal or capture of hazardous organics. Ash, scrubber water, and air pollution control device residues were typically below detection limits for POHCs and organics in general.

All incinerators and industrial process kilns tested met or approached the RCRA HCl removal standard. Industrial boilers typically have no existing controls for HCl, but none exceeded the 1.8 Kg/hr (4 lb/hr) emission standard since wastes with low net chlorine content were employed.

Achieving the particulate emission standard was a problem for a number of the incinerators tested. Four of the eight units failed to meet the RCRA standard. Two of those facilities were marginally above the emission limit they might be likely to meet the standard with minor operating adjustments. The remaining two facilities appeared to need significant design and/or operational changes. This general trend is consistent with the results of RCRA permit trial burns

conducted for other incineration facilities over the past two years. No significant changes in particulate emissions were observed for industrial boilers and certain of the industrial process kilns when they fired waste fuels. Some increased emissions were observed in kilns employing electrostatic precipitators (ESP) for particulate control. These increases were attributed to changes in the electrical resistivity of the particles due to the presence of increased chloride levels. Adjustments in ESP operation should correct this in most cases.

Analysis of the pooled data from the incinerator test program revealed that there was no absolute level of mean combustion temperature, mean gas phase residence time or carbon monoxide emission concentration which correlated with achieving 99.99 percent DRE. Residence times ranged from 0.1 to 6.5 seconds in the facilities tested. Temperatures ranged from 648°C to 1450°C. Carbon monoxide (CO) levels were as high as 600 ppm, but at most plants ranged from 5 ppm to 15 ppm. It appears at this time that the relationships between DRE and these parameters are in all likelihood facility specific and that waste characteristics, waste atomization, and combustion chamber mixing likely play an equally important role in achieving high DRE. Timing, funding, and facility constraints did not allow for collection of sufficient performance data under varying conditions at each site tested to allow for such relationships to be quantified. EPA is continuing to add new test results and information from permit trial burns and from testing at EPA pilot-scale research facilities to the data base in an effort to better predict DRE from process parameters.

While it may not now be possible to specify absolute levels of process operating parameters which will guarantee in advance that an incinerator will meet

the 99.99 percent DRE standard for a particular waste, efforts are being made to identify easily monitored process emissions which may be real time indicators of the onset of process failure to achieve acceptable DRE. Ongoing EPA research is striving to identify and quantify engineering relationships between typical incinerator process failure modes (e.g., inadequate waste atomization, overfeeding, etc.) and potential process performance indicator emissions such as carbon monoxide (CO), total unburned hydrocarbon (TUHC), oxygen (O_2), and emissions of potentially difficult-to-incinerate tracer compounds (sulfur hexaflouride, various freons) which could be "spiked" into the incinerator feed. Such relationships could be quantified during trial burns at each facility and subsequently be employed in process control by operators and in compliance assessment by regulators. This research is being conducted in bench- and pilot-scale thermal destruction research facilities in Cincinnati, Ohio; Research Triangle Park, North Carolina; and at EPA's unique Combustion Research Facility near Pine Bluff, Arkansas. Additional full-scale facility testing is also being conducted to assess the impact of non-steady-state or upset combustion conditions upon DRE and other indicator emissions.

(4) Incinerability

EPA has also examined the test data to try to correlate DRE values for POHCs as a function of the various approaches which have been suggested for determining a POHC's incinerability, or difficulty in being thermally destroyed. EPA guidance for selecting POHCs for a trial burn suggests that a compound's incinerability and concentration in the waste are important criteria.

The various methods which have been considered for incinerability ranking have been a matter of some scientific debate over the past several years. EPA

has recommended using a compound's heat of combustion as a POHC incinerability ranking criteria. Others have suggested the use of bond energies derived from theoretical kinetics, autoignition temperatures, and laboratory-scale thermal decomposition data to approximate compound incinerability. Analysis of pooled field test data indicated that no rigorous correlation could be found for DRE versus any of the ranking methods. More recent research, however, has suggested the use of an incinerability ranking based upon gas phase thermal stability data collected in laboratory-scale experiments under oxygen deficient conditions. Intercomparison of these stability data with appropriate field test data indicated that field thermal stability rankings were predicted by the laboratory data in 70 percent of the cases evaluated. Additional research is underway to expand the number of compounds for which intercomparisons can be made.

(5) Products Of Incomplete Combustion

The current RCRA standards regulate destruction and removal only for the major hazardous compounds in the waste. Under poor combustion conditions, many compounds may only partially decompose and form products of incomplete combustion (PICs) which are also hazardous compounds of concern if emitted. For the purpose of the EPA test program, compounds were considered to be PICs if they were regulated organic compounds (i.e., listed in Appendix VIII of CFR 40 Part 261) which were detected in stack emissions, but not present in the waste feed at concentrations greater than 100 ppm. The PICs most frequently identified in the EPA testing of incinerators and industrial boilers were benzene, chloroform, and tetrachloroethylene (Table 12). At this writing, detailed PIC analyses have been completed for only three cement kiln tests. The most common PICs identified during the kiln tests were benzene, benzaldehyde, toluene, and various naphthalenes.

TABLE 12--PICs MOST FREQUENTLY DETECTED IN STACK EMISSIONS

PIC	NUMBER OF FACILITIES	CONCENTRATION (ng/l)
Incinerators		
Benzene	6	12-670
Chloroform	5	1-1,330
Bromodichloromethane	4	3-32
Dibromochloromethane	4	1-12
Naphthalene	3	5-100
Bromoform	3	0.2-24
Chlorobenzene	3	1-10
Tetrachloroethylene	3	0.1-2.5
1,1,1-Trichloroethane	3	0.1-1.5
Toluene	2	2-75
o-Nitrophenol	2	25-50
Methylene chloride	2	2-27
Phenol	2	4-22
Boilers		
Chloroform	5	4.2-1900
Tetrachloroethylene	5	0.3-760
Chloromethane	4	4.6-410
Methylene chloride	4	83-2000
Benzene	3	9.4-270
1,1,1-Trichloroethane	3	5.9-270
1,2-Dichloroethane	3	1.3-1200
1,1-Dichloroethylene	2	0.21-38
1,1,2,2-Tetrachloroethane	2	4.6-16
Toluene	2	46-960

EPA is conducting continuing research to assess the nature and magnitude of PIC emissions from hazardous waste thermal destruction. Current data suggest that for thermal destruction facilities which are achieving good POHC DRE, PIC emissions are also very low and not of environmental concern. Consequently, the EPA does not currently have plans to regulate PICs under RCRA. Research, however, is striving to assure that potential PIC problems do not exist for wastes not yet tested or for marginal thermal destruction conditions (e.g., DRE failure conditions). Understanding the mechanisms for PIC formation and for PIC control through optimization of combustion conditions is therefore quite important.

E. Prospects For Thermal Destruction

The prospects for increased utilization of thermal destruction processes for hazardous waste disposal are significant. Incineration is a proven, commercially-available technology which has been demonstrated to be suitable for accommodating a wide range of wastes. Industrial high-temperature processes also can be suitably modified to destroy certain types of hazardous wastes (particularly combustible liquids) while recovering energy.

Thermal destruction is currently used to manage only about 2 percent of hazardous wastes generated annually. Many of the remaining wastes are being directed to land disposal facilities. However, the recently promulgated Hazardous and Solid Waste Amendments of 1984 (RCRA Amendments), with their sweeping provisions to restrict many wastes from land disposal, will prompt more intense consideration of thermal destruction as a control option.

EPA has estimated the amount of hazardous waste which might be redirected to commercial incineration as a result of restrictions upon disposal in landfills, lagoons, and injection wells. Each of these three restriction scenarios are

projected to result in an excess of commercial incineration demand over existing capacity of 215 to 306 percent for liquid wastes alone. Translated into facilities, this converts to as many as 26 incinerators (20,000 tonnes each), or incinerator ships (50,000 tonnes each). Solid hazardous waste and Superfund clean-up residues would further increase the shortfall.

While there are many boiler and kiln facilities which could dispose of waste, much of the waste which will become available for use in these thermal destruction facilities in the future is likely to be increasingly less attractive to them. This waste will tend to be much less combustible and higher in solids, ash, and water content and, therefore, more suited to more conventional commercial incineration facilities.

Permitting and siting difficulties are significant impediments to development of commercial incinerator capacity as well as use of industrial kilns for waste disposal. Consequently, available commercial incineration capacity is likely to grow little over the short-term. A three to five year lag-time is possible before significant new capacity could be available. Many believe that the use of mobile incinerators or larger but transportable units is one way of mitigating the public opposition which frequently plagues permanent centralized incineration facilities. While a number of mobile systems have been proposed, most are still developmental at this point. Little actual field testing has been done beyond that underway on an EPA-owned mobile rotary kiln incinerator. This unit has been tested for PCB and carbon tetrachloride destruction and is currently being tested to incinerate dioxin-contaminated soils in Missouri.

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